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POSSIBLE EFFECTS OF NOISE FROM OFFSHORE OIL AND GAS DRILLING ACTIVITIES ON MARINE MAMMALS: A SURVEY OF THE LITERATURE

CW Turl

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The Bureau of Land Management

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The acoustic environment in the area of offshore oil and gas drilling activities may influence the behavior of marine mammals. Increased noise levels may mask their acoustic signals. Offshore structures and the increased level of human activities in outer continental shelf areas could displace marine mammals from traditional feeding and breeding areas. No conclusions about the effects of noise on natural populations have been verified under controlled conditions.

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OBJECTIVES

1. Summarize the data on underwater noise generated from offshore drilling activities.

2. Summarize the data on underwater hearing capabilities of marine mammals.

3. Estimate the possible impact of noise from offshore drilling operations and associated human activities on natural populations of marine mammals.

RESULTS

1. Noise measurements from offshore drilling operations are sparse. Existing measurements are limited in bandwidth and are variable.

2. Some information is available on the underwater hearing sensitivity for a few species of marine mammals. However, without direct measurement of a species it is impossible to extrapolate to other species.

3. Information on the effects of subcritical levels of noise on animals is inconclusive. The effects of noise on natural populations of marine mammals is largely anecdotal. Therefore, the effects of offshore drilling noise on these animals based on present data cannot be determined.

4. No conclusions about the effects of stress on natural populations of marine mammals has been verified under controlled conditions.

RECOMMENDATIONS

1. Measure the noise generated from current and future offshore drilling operations. Include sensitive frequency ranges from known marine mammal audiograms.

2. Identify lease areas where offshore oil development is anticipated. Identify species of marine mammals that inhabit these areas.

3. Identify lease areas where introduction of increased sustained noise might disrupt a critical life cycle of marine mammals. For example, feeding, breeding, transit or congregation areas.

4. Initiate a monitoring program when a lease area is opened. Monitor both acoustic and population parameters in the lease area as development progresses.

5. Develop a program to monitor the effects of controlled introduction of noise to a marine mammal population. Quantify the effects of the noise on the population.

6. Obtain underwater audiograms of marine mammals that occur in the selected lease areas.

7. Determine the effects of noise on marine mammals under controlled conditions.

CONTENTS

INTRODUCTION . . . page 5

SUMMARY OF LITERATURE . . . 6

SUMMARY OF PUBLISHED DATA . . . 8

Estimated Source Levels . . . 8

Offshore Drilling Activities in the Prudhoe Bay Area . . . 8
Tufts Point Dredging Site/Arnak Artificial Island Construction Site . . . 12
Logistic Traffic Noise at the Tufts Point Site . . . 12
Semi-Submersible Platform in the North Atlantic . . . 12

UNDERWATER HEARING OF MARINE MAMMALS . . . 14

Sound Production and Hearing of Large Whales . . . 16

DISCUSSION . . . 18

RECOMMENDATIONS . . . 20

REFERENCES . . . 21

ILLUSTRATIONS

1 Average source level of noise generated from two drilling sites in Prudhoe Bay . . . 9
2 Average source level of noise generated from a construction site in the Beaufort Sea . . . 9
3 Average source level of noise generated from a construction site in the Beaufort Sea . . . 10
4 Maximum source levels of transient noise generated from a construction site in the Beaufort Sea . . . 10
5 Maximum source levels of the noise generated by logistic support traffic measured in the vicinity of a construction site in the Beaufort Sea . . . 11
6 Maximum source levels of the noise generated from a semi-submersible drilling platform located in the Atlantic Ocean . . . 11
7 Behavioral underwater audiograms (smoothed curves) for the beluga whale and the bottlenosed porpoise . . . 15
8 Behavioral underwater audiograms (smoothed curves) for the harbor porpoise and the killer whale.
9 Behavioral underwater audiograms (smoothed curves) for the California sea lion, the harp seal, the ringed seal and the harbor seal . . . 16
10 Summary of possible effects of offshore drilling noise on marine mammal population . . . 19

TABLES

1 Estimated distances from which noise from oil and gas drilling activities might be detected by marine mammals . . . 13
2 Summary of source level data for cetaceans . . . 17

INTRODUCTION

Increasing noise levels are the result of advanced technologies and rapidly growing human populations. Noise is a by-product of almost every aspect of human activity. Areas previously thought to be remote and nonpolluted by noise may soon have noise pollution from a variety of sources.

Offshore petroleum operations increased rapidly during the last decade and an even more rapid increase is anticipated for the next two decades. Noise generated during offshore drilling operations may become noise pollution for some acoustic sensors (ref 1). Early offshore drilling activities were concentrated in shallow water regions (eg, the Gulf of Mexico), but future exploration and production facilities will extend to water several thousand feet deep. These deep water noise sources will have better acoustic coupling to deep oceanic waters, and thus the noise may impact larger areas.

The Environmental Protection Agency (EPA) has identified the need for information on the effects of noise on wildlife (ref 2). The EPA recommended studies to determine (1) the effects of low-level chronic noise on animals, and (2) the effects of noise on animals in their natural habitat (ref 3, 4).

The Bureau of Land Management has identified two aspects of outer continental shelf gas and oil activities that may impact marine mammals: (1) the effects of underwater sounds emitted from oil and gas operations on cetacean behavior, and (2) the impact of offshore structures and associated human activities on cetacean populations.

The effects of noise on man and animals has been documented (see ref 5, 6 for review). The effects of noise are classified as (1) effects on the auditory system resulting in loss of hearing or damage to the auditory mechanism, or (2) nonauditory effects of noise.

In the first case, loss of hearing or damage to auditory structures can be produced by brief exposures to very intense sounds or prolonged exposures to moderate levels of sound. Noise with different frequency spectra have different effects on auditory structures. High frequency pure tones or narrow bands of noise tend to produce changes in localized regions of the inner ear. Low frequency or random and broadband noise tend to produce changes throughout the cochlea. The extent of noise-induced damage to the auditory system depends on the intensity, spectrum, duration and the exposure pattern of the noise source. Rest intervals between periods of exposure significantly reduce the extent of permanent damage.

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[1] Underwater Systems, Inc. Note 312-5, Noise measurements from Offshore Oil Rigs, p 17, Silver Springs, MD, 1973.

[2] Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, Environmental Protection Agency, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 1974.

[3] The White House, Executive Order No. 11644, as amended May 24, 1977.

[4] Janssen, R, Noise and Animals: Perspectives of Government and Public Policy, In: Effects of Noise on Wildlife, JL Fletcher and RG Busnel, ed, p 287-301, Academic Press, New York, NY, 1978.

[5] Kryter, KD, The Effects of Noise on Man, p 633, Academic Press, New York, NY, 1970

[6] Welch, BL and AS Welch, ed, Physiological Effects of Noise, p 365, Plenum, 1970.

Nonauditory effects of noise may produce physiological stress, with symptoms analogous to exposure to extreme heat or cold (ref 7, 8). An animal's response to stress includes a variety of measurable physiological changes; eg, increased blood pressure, increased cortiosteriod levels, and changes in adrenal gland weight. Prolonged stress can exhaust an animal's resistance to infection and disease and, in extreme cases, can result in the animal's death.

Noise produces the same general effects in animals and humans: namely, hearing loss, masking of signals, behavioral changes, and nonauditory physiological effects. Laboratory studies with animals indicate temporary and permanent noise-induced threshold shifts. However, damage risk criteria for most species of animals have not been developed. Physiological effects of noise exposure have been demonstrated in laboratory and farm animals, but the degree to which the results apply to wildlife is unknown. Animals' physiological and behavioral adaptations to noise stimuli are also yet unknown, and definitive research criteria to assess such adaptation have not been developed. In this report, however, judgments of environmental impact will be based on existing, though incomplete, information (ref 2).

The acoustic environment in areas of offshore drilling activities may influence the behavior of marine mammals. Increased noise levels may mask acoustic signals or reduce the range at which the mammals detect the signals (ref 9).

The impact of offshore structures and the associated increase in the level of human activities in outer continental shelf areas could disrupt normal migratory routes or displace marine mammals from traditional feeding and breeding areas. Such disruptions could reduce the biological fitness of a population.

This report summarizes (1) acoustic data from offshore drilling activities, and (2) the hearing capabilities of cetaceans and pinnipeds and presents data on the underwater hearing of large whales. The report also discusses the possible impact of offshore drilling activities on natural populations of marine mammals.

SUMMARY OF LITERATURE

Underwater noise measurements from offshore drilling activities are sparse. Published surveys and the author's personal contacts with private industry reveal that available information is bandwidth limited; ie, the measurements at high frequency were limited or the low frequencies were rolled off due to high ambient noise. Shallow water ambient noise measurements also are limited. In the shallow water of most offshore drilling operations (ie, less than 250 m) accurate source level noise measurements are difficult because of multipath propagation (ref 10). Variability is inherent in the data because sound propagation characteristics vary greatly in shallow water and ambient background noise is strong and variable in shelf areas.

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[7] Selye, H, Stress and Disease, Science, 122(3171), p 625-631, 1955.

[8] Selye, H, The General Adaptation Syndrome and the Diseases of Adaptation, J Clin Endocrin & Metab, 6(2), p 117-230, 1946.

[9] Myrberg, AA, Ocean Noise and the Behavior of Marine Animals: Relationships and Implications, In: Effects of Noise on Wildlife, JL Fletcher and RG Busnel, ed, p 168-208, Academic Press, New York, NY, 1978.

[10] Drouin, AH, Design and Field Operation of an Underwater Acoustic Telemetry System, Offshore Technology Conference, 6th, OTC 1965, p 9.

The source level data from offshore drilling activities specify the amount of sound energy radiated by a projector measured 1 m from the source.

The anatomy and function of the auditory and audio-neural structure of several species of small cetaceans have been reviewed (ref 11-16). Electrophysiological recordings and cochlear microphonic measurements (ref 13) support the hypothesis that sound is received via bone conduction through the fat layer of the lower jaw (ref 16) for small toothed whales.

The anatomical structure of the mysticete (large whales) auditory structure has been reviewed (ref 17-19). Mysticete cochlea are structurally sensitive to low frequency sounds; however, these animals may be capable of hearing higher frequencies (ref 20). Anecdotes suggest that large whales respond to ship noise, sonar pings and low flying aircraft (ref 21).

The pinniped external ear accommodates in-air and underwater hearing. Underwater, the pinniped head may conduct sound directly to the organ of Corti, whereas aerial sound transmission apparently is typically mammalian (ref 22).

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[11] Morgane, JP and NS Jacobs, Comparative Anatomy of the Cetacean Nervous System, In: Functional Anatomy of Marine Mammals, Vol 1, RJ Harrison, ed, p 117-244, Academic Press, New York, NY, 1972.

[12] Bullock, TH, AD Grinnel, E Ikezono, K Kameda, Y Katsuki, M Nomoto, N Sato and K Yanagisawa, Electrophysiological Studies of the Central Auditory Mechanism in Cetaceans, Z Vergl Physiol 59, p 117-156, 1968.

[13] McCormick, JG, EG Wever, J Palin and SH Ridgway, Sound Conduction in the Dolphin Ear, J Acous Soc Amer, 48(6), p 1418-1428, 1970.

[14] Wever, EG, JG Mc Cormick, J Palin and SH Ridgway, The Cochlea of the Dolphin, *Tursiops truncatus:* General Morphology, Proc Nat Acad Sci, 68(10), p 2381-2385, 1971.

[15] Fraser, FC and PE Purves, Hearing in Cetaceans, Bull of Brit Mus, 7, p 1-140, 1960.

[16] Norris, KS, The Echolocation of Marine Mammals, In: The Biology of Marine Mammals, HT Harrison, ed, p 391-423, Academic Press, New York, 1969.

[17] Reysenback de Haan, FW, Hearing in Whales, Acta Otolaryngal, 134, p 1-114, 1957.

[18] Dudok van Heel, WH, Sound and Cetacea, Neth J Sea Res, 1(4), p 407-507.

[19] Purves, PE, Anatomy and Physiology of the Outer and Middle Ear in Cetacea, In: Whales, Dolphin and Porpoise, KS Norris, ed, Univ of Calif Press, p 320-380, 1966.

[20] Fleischer, G, Hearing in Extinct Cetaceans as Determined by Cochlear Structure, J Paleontol, 50(1), p 133-152, 1976.

[21] Norris, KS and RR Reeves, eds, Report on a Workshop on Problems Related to Humpback Whales *(Megaptera novaeangliae)* in Hawaii, US Dept Comm, NTIS PB-280-794, p 90, 1978.

[22] Reppening, CA, Underwater Hearing in Seals, In: Functional Anatomy of Marine Mammals, RJ Harrison, ed, p 307-331, Academic Press, New York, 1972.

The techniques used to measure auditory thresholds of mammals have been reviewed (ref 23). Both behavioral or electrophysiological methods have been used to measure the hearing thresholds of marine mammals. Although an audiogram (ie, a measurement of hearing sensitivity as a function of frequency) describes an animal's hearing limits and regions of maximum sensitivity, it does not describe the animal's ability to hear a signal in the presence of background noise. To determine such detection ability, critical band or critical ratio data are required.

Audiograms indicate that cetaceans and pinnipeds are capable of hearing noise from offshore drilling activities. Data concerning marine mammals' reactions to such sounds are incomplete and essentially lacking.

SUMMARY OF PUBLISHED DATA

Source levels (dB re 1 μPa at 1m) for six offshore drilling activities are shown in figures 1 through 6. Estimated source levels were computed by taking the absolute received level measured at the hydrophone and applying propagation loss for the distance from the source so as to estimate the absolute level 1 m from the source.

Transmission loss in shallow water is sensitive to the environment, eg, sea surface, water depth and bottom type; therefore, spherical spreading loss (20 log R) is not appropriate. Reference 24 (figure 1) cites 40 log R to approximate sound propagation in the shallow water of Prudhoe Bay. Reference 25 (figures 2 through 5) approximates transmission loss as (20 log R + XR) + S[1]. For figure 2, X = .0045 dB, and for figures 3 through 5, X = .0075 dB. Spherical spreading (20 log R) was used to approximate the transmission loss in computing source levels for figure 6 (ref 26).

The source levels of specific frequency components contained in the noise spectrum shown in figures 1 through 3 (ref 24, 25) are based on maximum received levels measured at several distances from the source; therefore, the data in these figures are plotted as average source levels. Source levels shown in figures 4 and 5 (ref 25) and in figure 6 (ref 26) are based on maximum received levels measured at a single distance from the source. The data in these figures are plotted as maximum source levels.

ESTIMATED SOURCE LEVELS

Offshore Drilling Activities in the Prudhoe Bay Area

Figure 1 shows the major noise components from two drilling sites in the Prudhoe Bay area: the NIAKUK 3 well, on a man-made gravel island, and the Reindeer Island Cost Well, on a natural barrier beach island (ref 24). The source levels plotted are averages for received levels measured at ranges from 1000 to 1600 m.

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[23] Francis, RL, Behavioral Audiometry in Mammals: Review and Evaluation of Techniques, Symp Zool Soc Lond, 37, p 327-280, 1975.

[24] Bolt Beranek and Newman Inc Tech Memo 513, Measurements of Underwater Acoustic Noise in the Prudhoe Bay Area, by CI Malme and R Mlawski, p 16, 1979.

[25] Ford, J White Whale Offshore Exploration Acoustic Study, Report submitted to Imperial Oil Co, FF Slaney and Co, Ltd, Vancouver, Canada, p 21, 1977.

[26] Bell Laboratories, APEX Final Report, by SA Kramer and TE Wing, 1976.

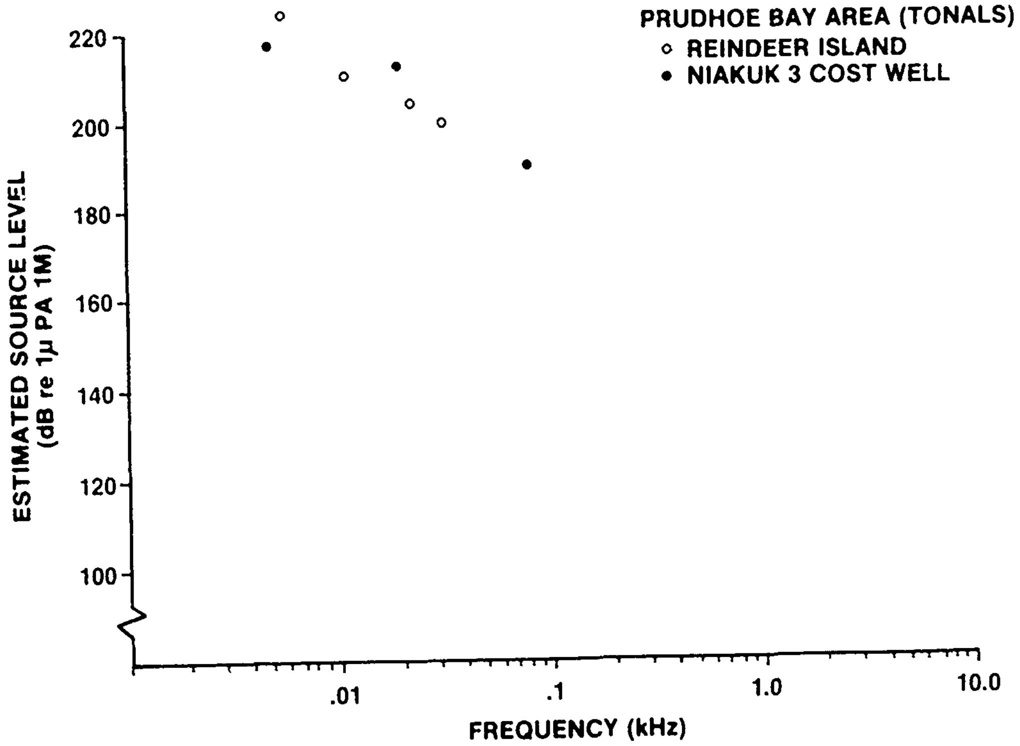

Figure 1. Average source level of noise generated from two drilling sites in Prudhoe Bay.

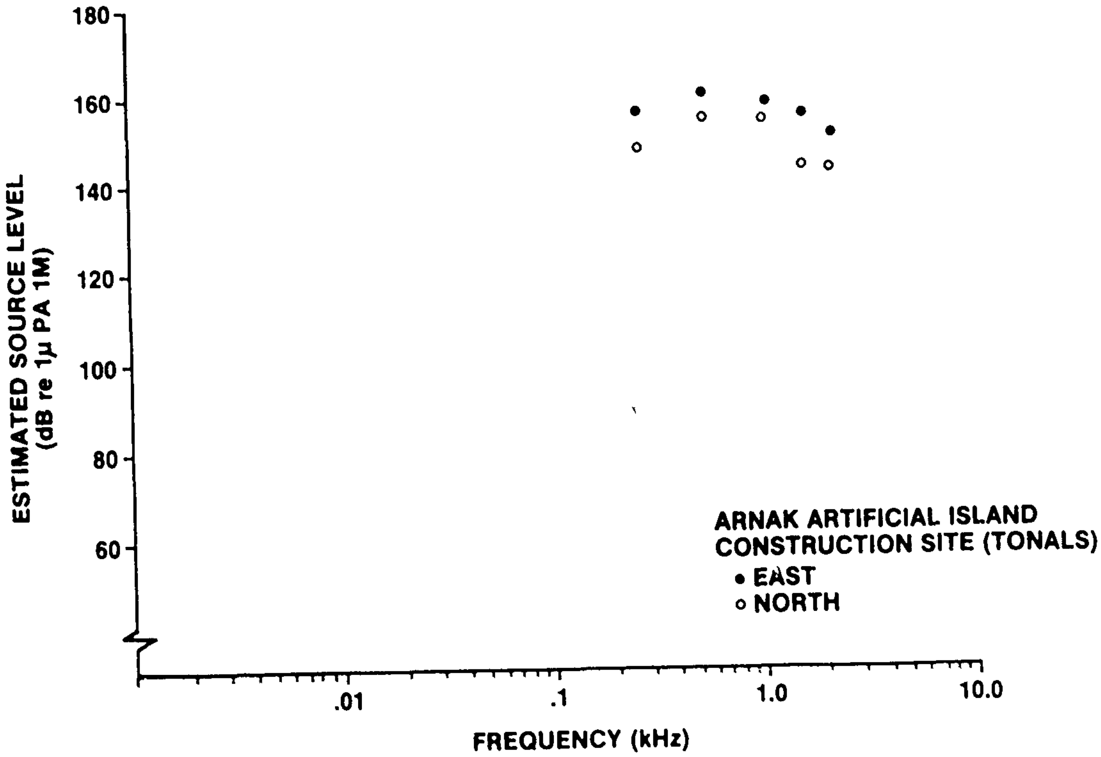

Figure 2. Average source level of noise generated from a construction site in the Beaufort Sea.

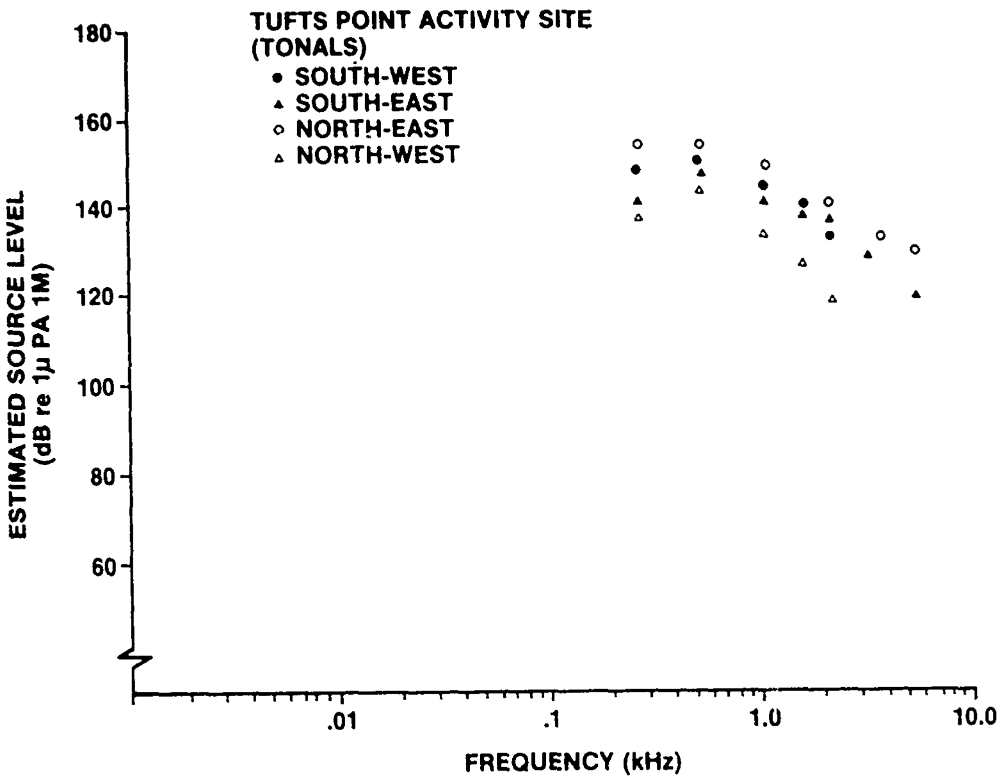

Figure 3. Average source level of noise generated from a construction site in the Beaufort Sea.

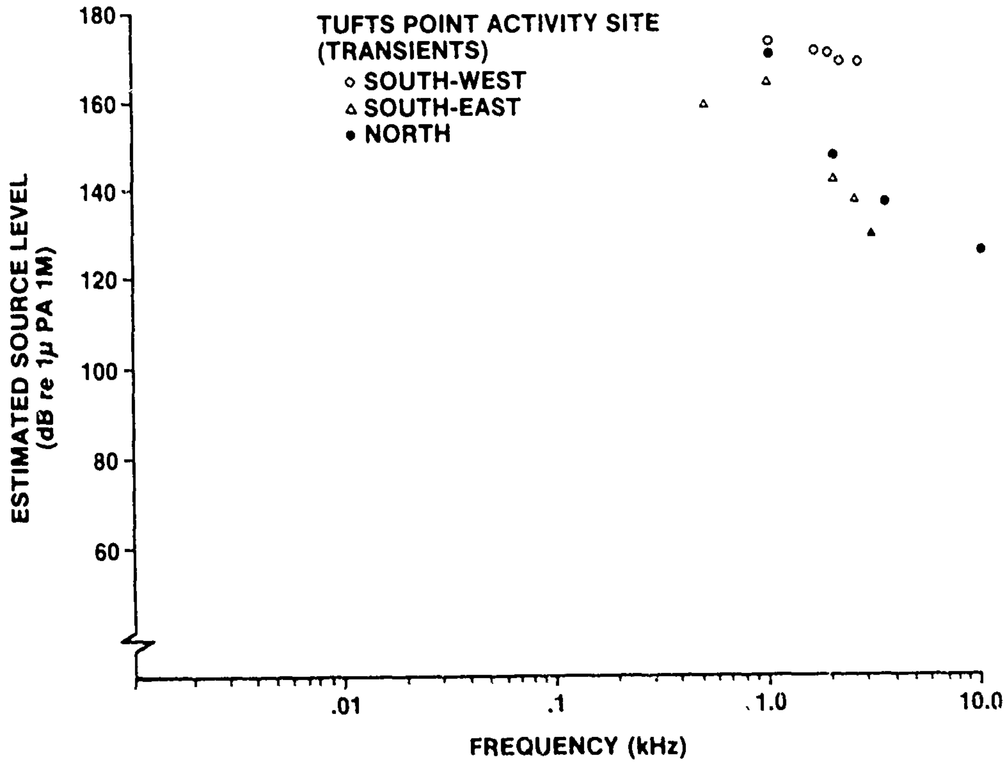

Figure 4. Maximum source levels of transient noise generated from a construction site in the Beaufort Sea.

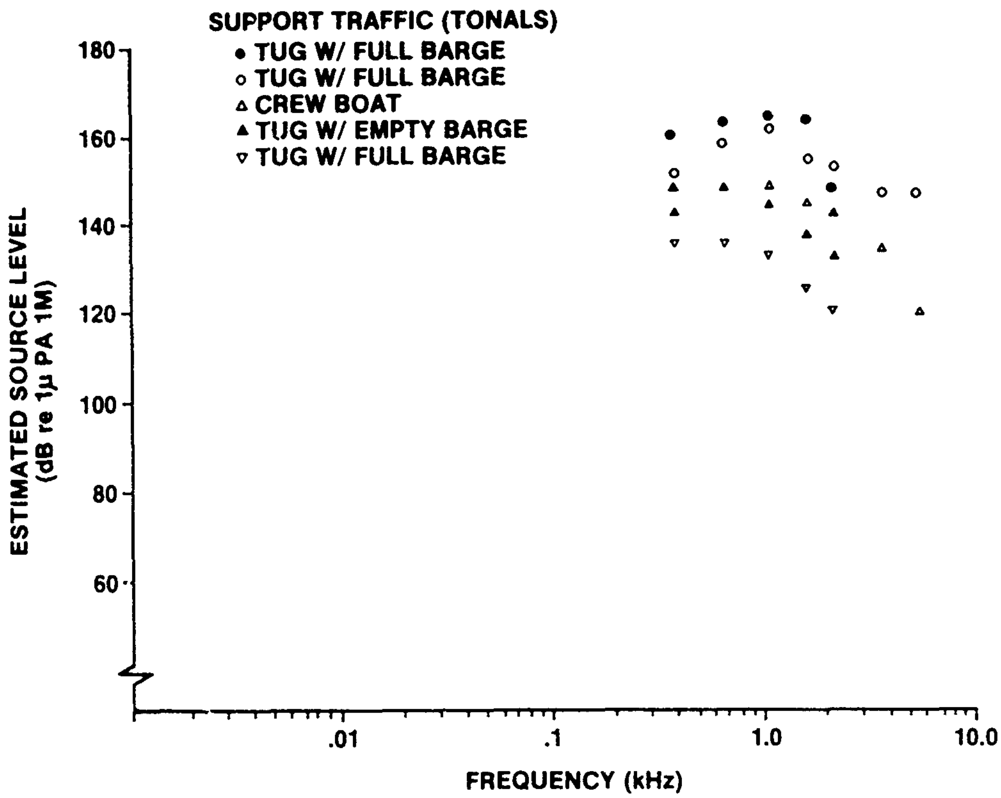

Figure 5. Maximum source levels of the noise generated by logistic support traffic measured in the vicinity of a construction site in the Beaufort Sea.

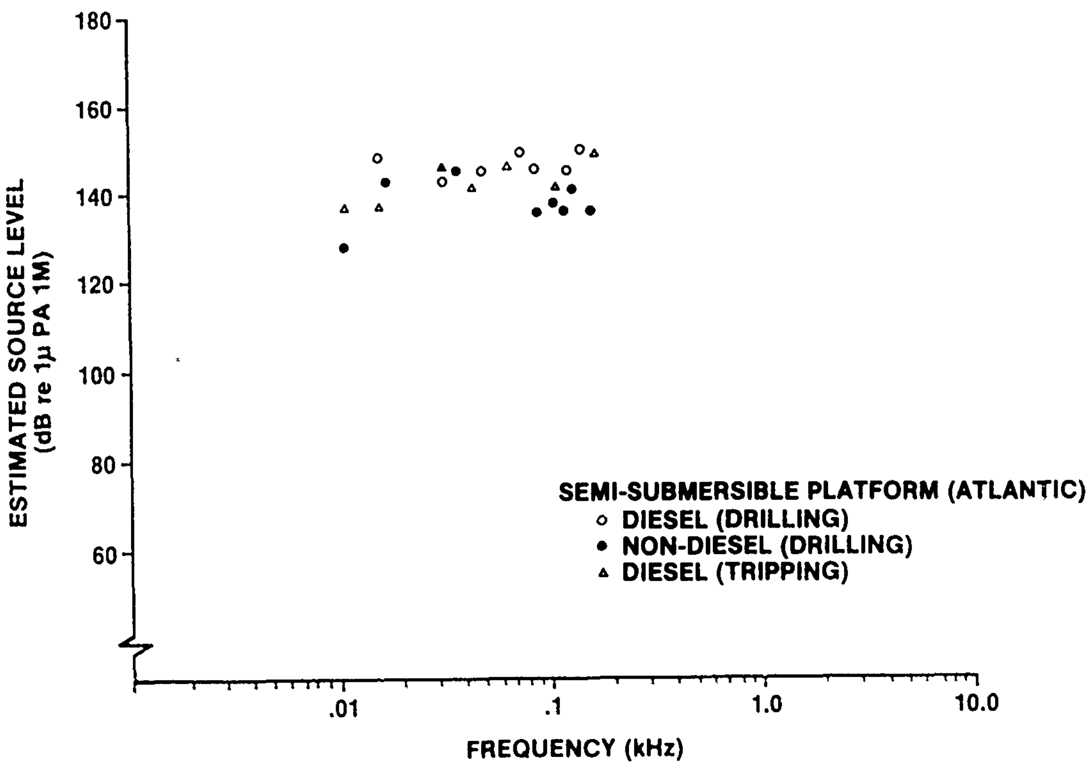

Figure 6. Maximum source levels of the noise generated from a semi-submersible drilling platform located in the Atlantic Ocean.

Although the Prudhoe Bay data show little difference in noise level, the noise components at each site differ. The authors (ref 24) note that the noise levels above 8 kHz were low.

Tufts Point Dredging Site/Arnak Artificial Island Construction Site

Figures 2, 3 and 4 show the noise generated from two construction locations in the Beaufort Sea (ref 25). The sounds are from construction activities associated with development of offshore operations.

At the Arnak artificial island site, operating machinery included a suction dredge, a tending tug, a clamshell shovel, and several crew boats. Figure 2 shows the noise components from this site. The frequency band and amplitudes from the Tufts Point and Arnak sites are similar. Data were not reported for frequencies below 250 Hz (ref 25).

At the Tufts Point dredging site, noise sources included a suction dredge, crew boats and tugs. Noise measurements were made at ranges from 90 to 4000 m in four different directions from the site. An artificial breakwall extends northwest from the site and probably limited noise from that direction (fig 3). The average noise levels from the other three directions are similar in frequency and higher than values measured from the northwest.

Transient sounds also were recorded at the Tufts Point site. Noisy couplings in the floating pipeline probably produced the short-duration sounds plotted in figure 4.

Logistic Traffic Noise at the Tufts Point Site

Figure 5 shows the noise generated from tugs, tugs pushing barges (empty and full) and crew boats at the Tufts Point site. The frequency spectra and amplitudes are comparable to those in figure 2. The isolated sources shown in figure 5 also were included in the composite sounds shown in figure 2.

Semi-Submersible Platform in the North Atlantic

Figure 6 shows source levels for low frequency component noise from a semi-submersible drilling platform in the North Atlantic (ref 26). These values are similar to those shown in figure 1, but the amplitude varies less with frequency. The Atlantic measurements are from a single, distant measuring site in deep water, and thus likely less variable than the Arctic measurement.

Data in figures 1-6 show noise from offshore oil and gas drilling activities is in the frequency range from 10 Hz to 10 kHz, with peak source levels between 130 and 180 dB. Signal-to-noise (S/N) ratios may approach 80 to 100 dB above background noise levels (ref 27). Depending on the detection threshold of the receiver and the prevailing background noise levels, S/N levels of these magnitudes could be detected at considerable ranges from the source.

To estimate distances at which a marine mammal could detect a component of noise with source levels shown in figures 1-6, a transmission loss model for deep or shallow water propagation must be selected. Either model includes a number of assumptions concerning the characteristics of the receiving system. (Information on the hearing for large whales is discussed in the following section.) These assumptions are:

[27] Urick, RJ, Principles of Underwater Sound, p 384, McGraw-Hill Book Co, 1967.

- The underwater hearing of large whales is optimized. Because the ocean is a noisy place, an acoustic system will be limited by noise before it is limited by sensitivity; therefore, a detection threshold of 0 dB will be required for a signal to be heard 50 percent of the time.
- The hearing bandwidth is 1/3 octave.
- The receiver is omnidirectional.

In deep water (greater than 100 fathoms), a good approximation for transmission loss is given by spherical spreading (20 log r). The estimation detection range can be approximated by:

$$\text{Range (m)} = 10^{\left[\frac{SL_{(peak)} - (N_S + 10 \log BW)}{20}\right]}$$

Where: $SL_{(peak)}$ = Peak source level (dB re 1 μPa at 1 m)
N_S = Background noise level (dB re 1 μPa)
BW = Critical bandwidth at the frequency of the signal.

Attenuation is also a factor in range determinations. The attenuation coefficient (α) is frequency dependent, and at frequencies below 1 kHz is approximately 0.05 dB/kyd. In the following calculations attenuation was considered insignificant and was ignored.

In shallow water, transmission loss is sensitive to many variables, particularly the sea surface, the water medium and the bottom. Thus, in the absence of specific knowledge of the variables, especially the sound velocity and density structure of the bottom, transmission loss in shallow water is only approximately predictable (see ref 27). Therefore, for shallow water, the formula above at best approximates a "minimal detectable range" in the absence of further information.

The values in table 1 show that noise generated from oil and gas drilling activities may be detected at considerable distances from the drilling sites. Favorable propagation characteristics could extend these ranges further.

FREQUENCY (kHz)	SOURCE LEVEL (dB)	BACKGROUND NOISE (dB)	BANDWIDTH (Hz)	RANGE		AREA OF A CIRCLE WITH A RADIUS = TO RANGE (SQ NMI)
				Kilometers	NMI	
0.02	160	60	8	38	21.0	1.3×10^3
0.10	150	50	15	17.4	9.3	2.7×10^2
1.00	180	50	25	174	94.0	2.8×10^4

Table 1. Estimated minimum distances from which noise from oil and gas drilling activities might be detected by marine mammals.

UNDERWATER HEARING OF MARINE MAMMALS

Behavioral underwater audiograms have been made for the bottlenose dolphin, *Tursiops truncatus* (ref 28), the harbor porpoise, *Phocoena phocoena* (ref 29), the killer whale, *Orcinus orca* (ref 30), the white whale, *Delphinapterus leucas* (ref 31), and the Amazon river dolphin, *Inia goeffrensis* (ref 32). Audiograms for the bottlenosed dolphin, the killer whale, the harbor porpoise and the white whale are shown in figures 7 and 8.

Underwater audiograms also have been made for four species of pinnipeds: the California sea lion, *Zalophus californianus* (ref 33), the harp seal, *Pagophilus groenlandicus* (ref 34), the ringed seal, *Pusa hispida* (ref 35), and the harbor seal, *Phoca vitulina* (ref 36). Figure 9 shows the underwater audiograms for these four species.

Electrophysiological audiograms have been made for both cetaceans and pinnipeds. Bullock et al (ref 12) tested anesthetized animals, including the striped dolphin, *Stenella coeruleoalba,* the spotted dolphin, *Stenella attenuata,* the rough-toothed dolphin, *Steno bredanensis,* and the Pacific bottlenosed dolphin, *Tursiops gilli.* Interspecific sensitivities were similar and resembled the behavioral audiogram for *Tursiops truncatus* (ref 28). Evoked potentials were used to determine an audiogram for an unrestrained, alert grey seal, *Halichoerus grypus* (ref 37).

Figures 7 through 9 show underwater audiograms for eight species of marine mammals. The data shown in these figures indicate that the marine mammals tested were relatively insensitive at low frequencies. Most underwater threshold experiments have been conducted in small tanks that introduced serious measurement problems because of the sound field in the tank (ref 38). Consequently, the low frequency thresholds for marine mammals have not been documented adequately.

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[28] Naval Ordance Test Station TP 4178, Auditory Thresholds in the Bottlenose Porpoise, *Tursiops truncatus,* by CS Johnson, p 22, 1966.

[29] Andersen, S, Auditory Sensitivity in the Harbor Porpoise, *Phocoena phocoena,* In: Investigations on Cetacea, Vol 2, G Pilleri, ed, p 255-258, 1970.

[30] Hall, JD and CS Johnson, Auditory Threshold of a Killer Whale, *Orcinus Orca,* J Acous Soc Amer, 41(1), p 515-517, 1971.

[31] Hubb Sea Work Research Institute Technical Report 78-109, Auditory Thresholds of Two Beluga Whales *(Delphinapterus leucas),* by MJ White, JC Norris, DK Ljunblad, KS Baron and GN DeSciara, p 13, 1978.

[32] Jacobs, DW and JD Hall, Thresholds of a Freshwater Dolphin, *Inia geoffrensis,* J Acous Soc Amer, 51(1), p 530-533, 1972.

[33] Schusterman, RJ, RF Balliet and J Nixon, Underwater Audiogram of the California Sea Lion by Conditioned Vocalization Techniques, J Exp Anal Beh, 17, p 339-350, 1972.

[34] Terhune, JM and K Ronald, The Harp Seal, *Pagophilus groenlandicus,* III, The Underwater Audiogram, Can J Zool, 50, p 565-569, 1975.

[35] Terhune, JM and K Ronald, Underwater Hearing Sensitivity of Two Ringed Seals *(Pusa hispida),* Can J Zool, 53, p 227-231, 1975.

[36] Mohl, B, Auditory Sensitivity of the Common Seal in Air and Water, J Aud Res, 8, p 27-38, 1968.

[37] Ridgway, SH and PL Joyce, Studies on Seal Brain by Radiotelemetry, In: Biology of the Seal, K Ronald and AW Mansfield, eds, p 81-91, 1975.

[38] Parvulescu, A, The Acoustics of Small Tanks, In: Marine Bioacoustics, WN Tauolga, ed, p 7-13, Pergammon Press, 1967.

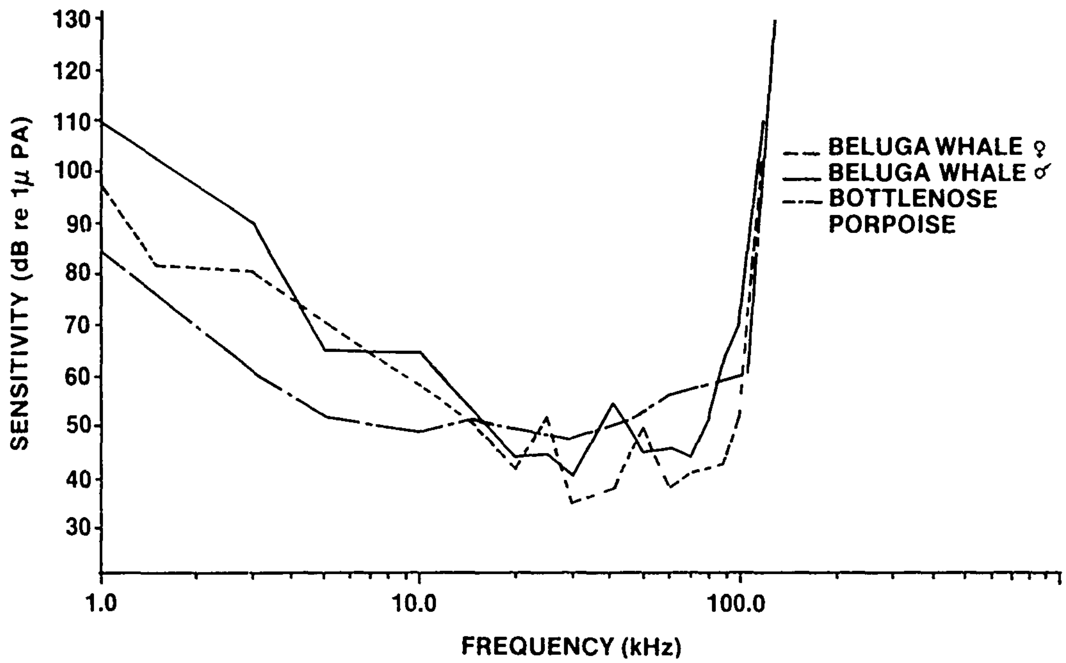

Figure 7. Behavioral underwater audiograms (smoothed curves) for the beluga whale and the bottlenosed porpoise.

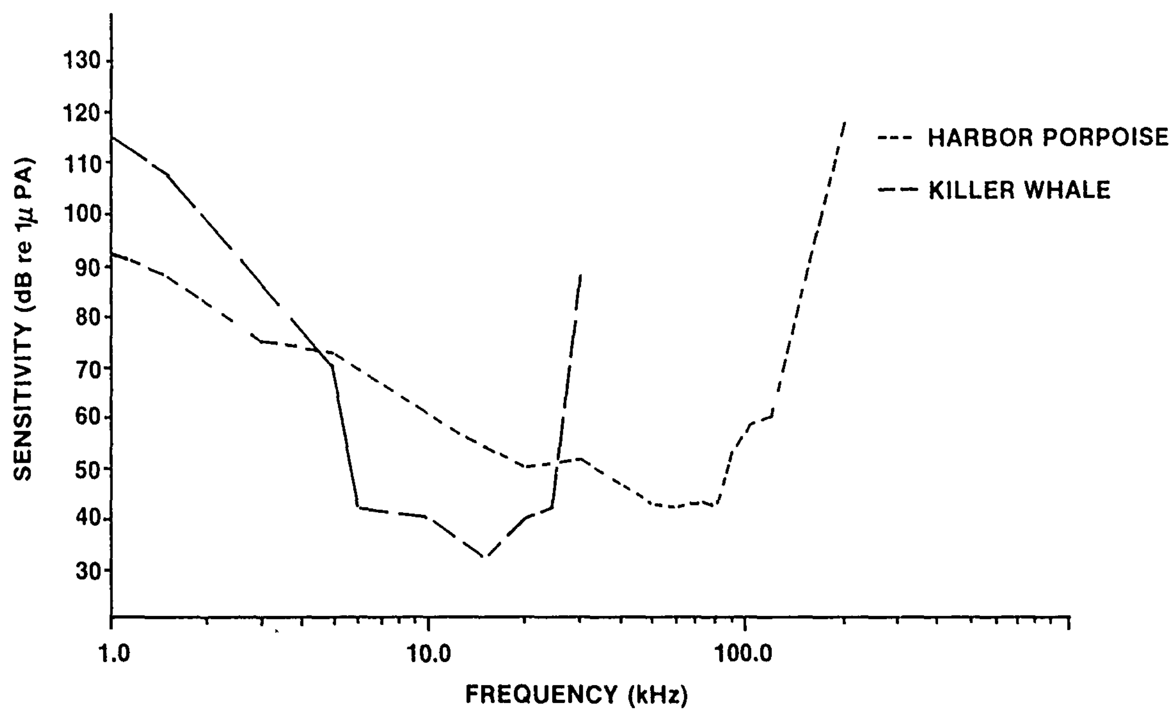

Figure 8. Behavioral underwater audiograms (smoothed curves) for the harbor porpoise and the killer whale.

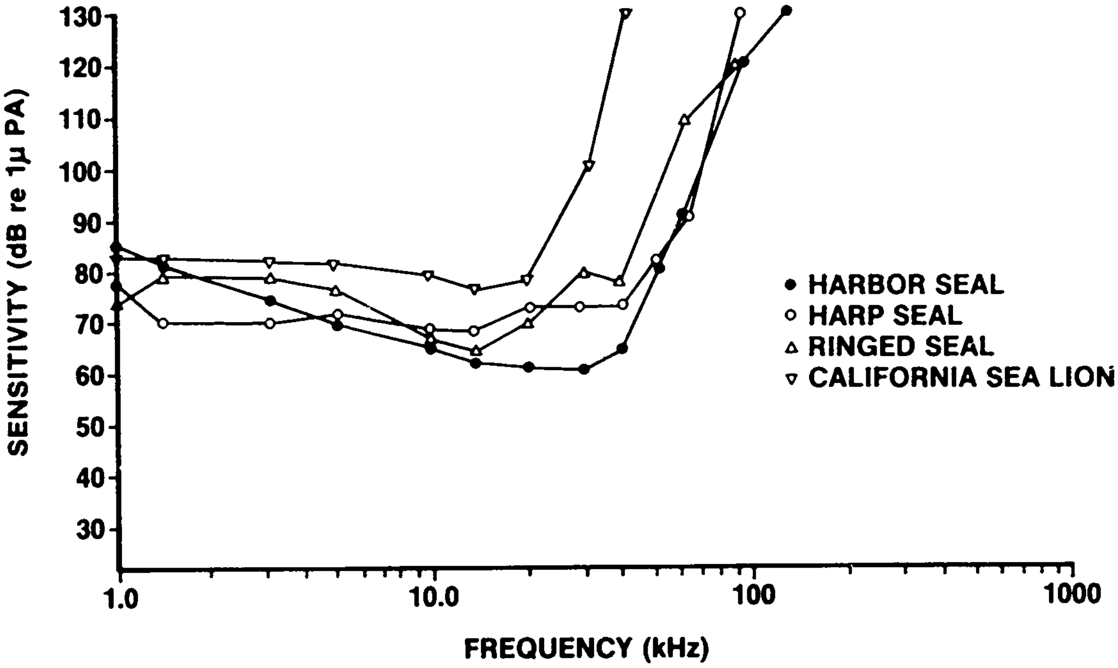

Figure 9. Behavioral underwater audiograms (smoothed curves) for the California sea lion, the harp seal, the ringed seal and the harbor seal.

SOUND PRODUCTION AND HEARING OF LARGE WHALES

The hearing sensitivities of large whales have not been measured. It is assumed that most animals can hear the sounds they produce; however, we cannot determine the limit of the receiving bandwidth of large whales without direct measurements. Source level and frequency data for cetaceans are summarized in table 2. These reported values are peak energy levels in relatively narrow bands. Broadband source level measurements are presented in reference 39 for four species of small toothed whales (the common dolphin, the northern right whale dolphin, the Pacific pilot whale and the Pacific bottlenosed dolphin). The values shown in table 2 suggest that sounds produced by large whales are restricted in frequency; however, these values probably reflect the manner in which source level data normally are presented as narrow band measurements.

Reference 58 classifies mysticete sounds into four categories. Group I includes low frequency moans with fundamental frequencies from 12 to 500 Hz. The moans generally contain harmonically structured pure tones. Except for the sei and minke whales, all mysticetes make these sounds. Group II sounds include grunt-like thumps and knocks of short duration. The humpback, right, bowhead, grey, fin and minke whales produce these sounds. Major energy in Group II sounds is between 40 and 200 Hz. Group III sounds contain chirps, cries and whistles above 1.0 kHz. Chirps generally are pulses of short, discrete,

[39] Naval Undersea Center TP 547, Acoustic Source Levels of Four Species of Small Whales, by JF Fish and CW Turl, p 14, 1976.

[58] Thompson, TJ, HE Winn and PJ Perkins, Mysticete Sounds, In: Behavior of Marine Mammals, Vol 3, Cetaceans, HE Winn and BL Olla, eds, p 403-431, Plenum Press, 1979.

SPECIES	SOURCE LEVEL (dB, re 1 μPa @ 1 m)	FREQUENCY	REFERENCE NUMBER
ODONTOCETE			
Tursiops truncatus	217-228	Broadband peak-to-peak level of clicks.	40
	175	Broadband peak-to-peak level of clicks.	41
Lagenorhynchus australis	80	Broadband RMS level of clicks.	42
Orcinus orca	160	Broadband RMS level of screams (click trains)	43
Stenella lognirostris	108-115 109-125 85-95	Broadband R,S levels of pulse bursts. "squeals" clicks	44
Inia geoffrensis	165	Broadband peak-to-peak levels of clicks.	45
Phocena phocena	100	Broadband RMS level of clicks.	46
	140	Mean and range of peak broadband levels of click.	43
Physeter catadon	135	Peak broadband level of pulses thought to be *P. catadon*.	47
	173.5	Mean 1/3-octave level of clicks at 1 kHz.	48
	171.5 (165.5-175.3)	Mean and range of broadband level of clicks.	49
MYSTICETE			
Megaptera novaeangliae	138.6 148.6 155.4 (144.3-174.4)	Mean 1/3-octave level at 5 kHz. Mean 1/3-octave level at 1 kHz. Mean and range of broadband levels of various types of signals.	50
Eubalaena glacialis	172-187	Levels in the 25-2500-Hz band for belch-like sounds.	51
Eschrichtius glaucus	138-152	Mean broadband levels for several different types of low-frequency signals. Highest level measured.	52
Balaenoptera musculus	159.2	Maximum broadband level of clicks.	53
	188	Mean level of moans in a 14-222-Hz band.	54
Balaenoptera physalus	173-181	Source level for 20-Hz pulses.	55
		Source level of 20-Hz pulses thought to be from *B. physalus*, based on source level calculations as cited in reference.	56
Balaenoptera acutorostrata	152-6	Maximum broadband level of clicks.	57

Table 2. Summary of source level data for cetaceans (from reference 39).

nonharmonic tones which change frequency rapidly. Cries and whistles are pure tones with or without harmonics. Group IV are clicks or pulses which have peak energy at high frequencies, often between 20 and 30 kHz.

Two types of sounds have been recorded from bowhead whales: a short duration and a long duration sound. The sounds' fundamental frequencies are 50-80 Hz and 100-195 Hz, respectively (ref 59).

The hearing thresholds for large whales have not been measured. If the sounds produced by these whales are indications of sounds they could receive, then the whales' hearing bandwidth extends from 12 Hz to 30 kHz.

DISCUSSION

Excess or increased environmental noise could impact animals that rely on acoustic signals to maintain biological functions such as feeding, mating, and protecting and raising young. No standards exist to evaluate the effects of noise on marine mammals and we lack data on the auditory sensitivity for many species of marine mammals, particularly the large whales. Data on the effects of sustained, low levels of noise on biological functions also is sparse. Thus, in this report we cannot quantify the effects of offshore drilling operations on marine mammals.

The acoustic characteristics of the 20-Hz sound produced by the fin whale, *Balaenoptera physalus* (ref 60), is described as a signal well suited for long range communications. The authors surmise that a decrease in the signal-to-noise ratio, either at the source or the receiver, could sustantially reduce the detection range.

Reference 61 showed that as the noise level in the vicinity of an echolocating dolphin increased, the number of clicks increased (echolocation effort). Furthermore, overall detection performance was degraded with increased noise levels.

Reference 62 suggests that increased shipping activities in Japanese waters have resulted in altering the historical migration routes of the Baird's beaked whale, *Berardius bairdi,* and the minke whale, *Balaenoptera acutorostrata.* Although additional factors may be affecting these populations, the impact of increased maritime activities in whaling grounds should be considered as a potential disrupting influence.

Figure 10 summarizes some possible effects of offshore drilling noise on marine mammal populations. Noise can be classified as either chronic or acute. Chronic noise will either mask signals or induce stress that may become manifest either physiologically or behaviorally. Acute noise may reduce the animal's ability to perceive a signal. Both acute and chronic noise can cause short-term disruption of critical behaviors or mask intraspecific transmission of information. If a population cannot adapt or accommodate to the short-term

[59] Ljungblad, DK, S Leatherwood and ME Dahleim, Sounds Recorded in the Presence of an Adult and Calf Bowhead Whale, *Balaena mysticetus,* Naval Ocean Systems Center TR 420, p 1-7, 1979.

[60] Payne, R and D Webb, Orientation by Means of Long Range Acoustic Signaling in Baleen Whales, New York Acad Sci, 188, p 110-141, 1971.

[61] Penner, RH and J Kadane, *Tursiops* Biosonar Detection in Noise, In: Animal Sonar Systems, RF Busnel and JF Fish, eds, p 957-959, Plenum Press, 1980.

[62] Nishiwake, M and A Sasao, Human Activities Disturbing Natural Migration Routes of Whales, Sci Rep Whales Res Inst, 29, p 113-120, 1977.

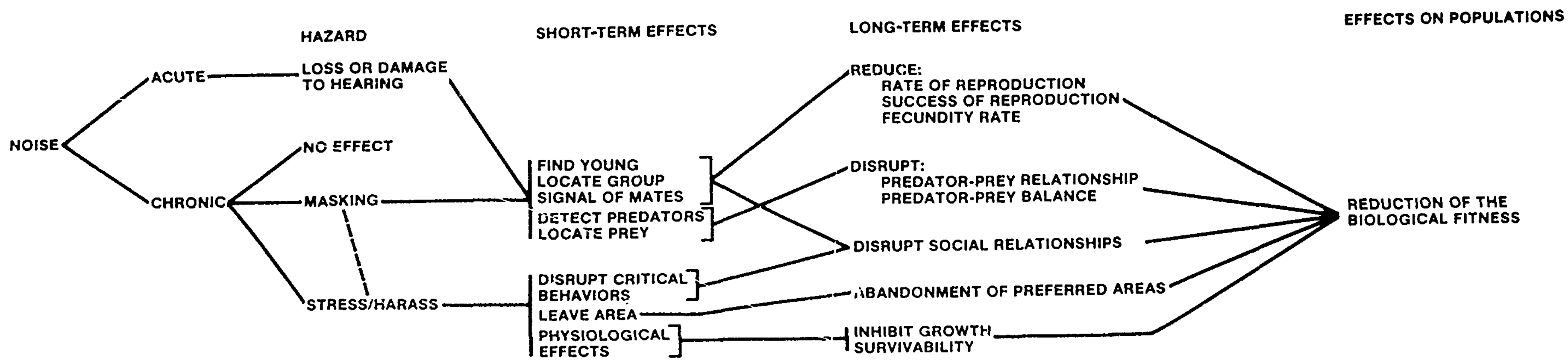

Figure 10. Summary of possible effects of offshore drilling noise on marine mammal populations.

effects, then the long-term effects of noise may reduce the population's reproductive capabilities, disrupt predator-prey relationships, or cause a population to abandon preferred breeding or feeding areas.

The above discussion deals only with the possible effects of noise on marine mammals. Data are not yet available to determine the probability of such effects occurring or to evaluate the severity of the effects on wild populations of animals. Damage risk criteria that have been established for humans may not be appropriate in evaluating possible effects of noise on wildlife (ref 63), because the amount of physiological and behavioral adaptation that occurs in response to noise stimulus is unknown.

Continuous noise levels above 90 dBA (approximately 115 dB re 1 μPa at 1 m in water) have potentially detrimental effects on human performance and noise levels of less than 90 dBa can be disruptive (ref 2). Until noise standards are established for wild animals, we may assume that animals will be at least partially protected by applying maximum levels identified for humans.

RECOMMENDATIONS

1. Measure the noise generated from current and future offshore drilling operations. Include sensitive frequency ranges from known marine mammal audiograms.

2. Identify lease areas where offshore oil development is anticipated. Identify species of marine mammals that inhabit these areas.

3. Identify lease areas where introduction of increased sustained noise might disrupt a critical life cycle of marine mammals. For example, feeding, breeding, transit or congregation areas.

4. Initiate a monitoring program when a lease area is opened. Monitor both acoustic and population dynamic parameters in the lease area as development progresses.

5. Develop a program to monitor the effects of controlled introduction of noise to a marine mammal population. Quantify the effects of the noise on the population.

6. Obtain underwater audiograms of marine mammals that occur in the selected lease areas.

7. Determine the effects of noise on marine mammals under controlled conditions.

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[63] Fletcher, JL and RF Busnel, eds, Summary and Discussion, In: Effects of Noise on Wildlife, p 303-305, Academic Press, 1978.

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